07 Apr 1995, 10:30 am - 11:30 am

Discussions and Replies — Session IX

Multiple Authors

DISCUSSIONS AND REPLIES SESSION IX

Discussion on papers: "Site Dependent Ground Response for the City of Patras, Greece" by G.A. Athanasopoulos, "Review of Geotechnical Investigations Resulting from the Roermond April 13, 1992 Earthquake" by P.M. Maurenbrecher et al, "Soil-Response Analyses for the 1990 South-East Sicily Earthquake" by M. Maugeri and S.M. Frenna. Papers #9.04,9.16,9.17

By: Michele Maugeri, Faculty of Engineering, University of Catania, Italy.

1. Introduction

The three papers refer to earthquakes of similar magnitudo and then they can be discussed together, with particular reference to the effects of soil properties on seismic motion, the soil analysis response and the microzoning criteria.

2. Recent earthquakes

The earthquake recorded at the city of Patras in Greece on July 14, 1993 has shown an estimate magnitudo of M_s = 5.4 almost equal to that shown by the earthquake recorded in South-East Sicily, Italy, on December 13, 1990, and very close to the magnitudo of M_s = 5.8 shown by earthquake recorded in Roermond, Oland, on April 13, 1992.

These similar earthquakes caused different soil motions in terms of acceleration, velocity and displacement. During the Patras earthquake the surface acceleration was found ranging from 0.10g in the coastal region to 0.50g in the inland area, while during the Sicilian earthquake the surface acceleration was found ranging from 0.10g at the Sortino City in rock ground, up to 0.25g in the city of Catania in soft ground; during the Roermond earthquake the maximum accelerations recorded are not quoted by the Authors, however from figure 4 (Maurenbrecher et al, 1995) the maximum soil response acceleration can be extimated around 0.1g. In spite of similar magnitudo the earthquakes caused different victims.

The biggest damage was caused by the South-East Sicily earthquake where the remedial works to public structures and to stabilize landslides were extimated to US $ 42 million. About 10 times more was the damage suffered by private house. The earthquake caused also 19 deaths, some of them due to heart failure. In the case of the Roermond earthquake remedial works to structures amounted to US $ 50 million and only 1 death in Germany, due to heart failure, has been attributed to the earthquake. The amount of damage and the number of deaths was not reported for the Patras earthquake in the paper by Athanasopoulos (1995). Perhaps it is not mentioned because the damage was very little and no deaths occured.

3. Effects of soil properties on seismic ground motion

For a reliable prediction of a seismic ground motion an accurate site investigation is needed to detect soil profile and dynamic soil properties. This has been well done for the three papers. In the paper by Athanasopoulos (1995) 20 soil profiles in 20 different sites were checked for the city of Patras, while four soil profiles were checked for a single damaged building site in the city of Augusta (Maugeri and Frenna, 1995); the number of boreholes and others in situ test are not quoted by Maurembrecher et al (1995) for the Roermond earthquake but they seem to be very numerous.

The number of soil profile and related in situ tests is very important for an accurate prediction of seismic ground motion because that the average soil response of a number of given sites could be very different from soil response of the average profile. Then the soil profiles available must be enough to detect typical zones of the given city. Soil Dynamic properties for the city of Patras were detected by means of the correlation (Athanasopoulos, 1995):

$$V_s(\text{m/sec}) = 107.6\,(N_{SPT})^{0.36} \qquad (1)$$

In figure 1 is reported a comparison between this correlation with other similar correlations given by some Authors. It can be seems from figure 1, that there is a good agreement between Patras clay soil and Calabritto (Italy) clay soil (Maugeri and Carrubba, 1983).

Similar correlations between shear modulus at small strain G_0 and cone penetration tests (CPT) were detected by Maurenbrecher et al (1995) for the city of Roermond, but the correlations laws are not reported in the paper.

For the site of a damaged building in Augusta, together with the four boreholes, SPT tests, CPT tests and flat dilatometer tests (DMT Marchetti, 1980), were performed (Maugeri and Frenna, 1995). From the results obtained by these different in situ tests the best prediction of the shear modulus at small strain G_o was detected by DMT test results, according to the correlation (Hryciw, 1990):

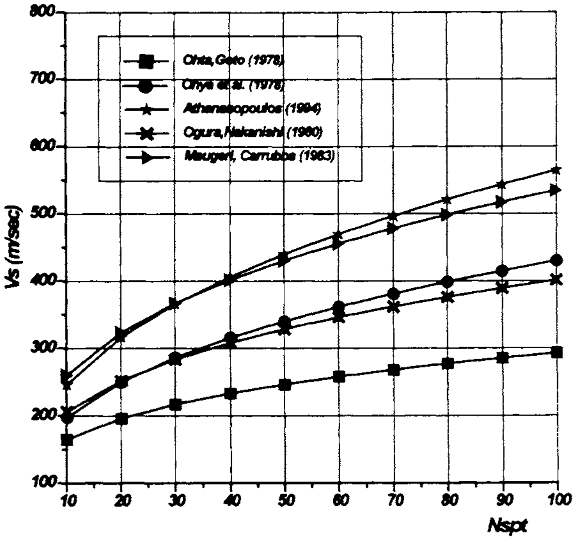


Fig.1 - Correlations of shear waves velocities versus N_{SPT} for different sites

$$G_o = \frac{530}{\left(\frac{\sigma'_v}{P_a}\right)^{0.25}} \bullet \frac{\left(\frac{\gamma_D}{\gamma_w}\right) - 1}{2.7 - \left(\frac{\gamma_D}{\gamma_w}\right)} k_o^{0.25} (\sigma'_v P_a)^{0.5} \qquad (2)$$

where σ'_v (bar) is the effective vertical stress, γ_w (t/m³) is the unit weight of water, γ_D (t/m³) is the total unit weight of the soil, k_o is the coefficient at rest pressure and P_a is the unit atmosphere pressure. The evaluation of G_o according to equation (2) has been made for the values of γ_D and k_o obtained from DMT test. γ_D (t/m³) evaluated according to figure 1 of Hryciw's (1990) paper, was ranging between 1.60 at the top and 2.00 t/m³ at the depth of 28 meters; k_o, evaluated according to Marchetti (1980) relationship, was ranging between 0.75 at the top and 1.4 at the depth of 28 meters. The validation of equation (2) with the results obtained from resonant column tests is given in fig.2.

Resonant column tests are needed to evaluate shear modulus degradation G_γ versus shear deformation γ.

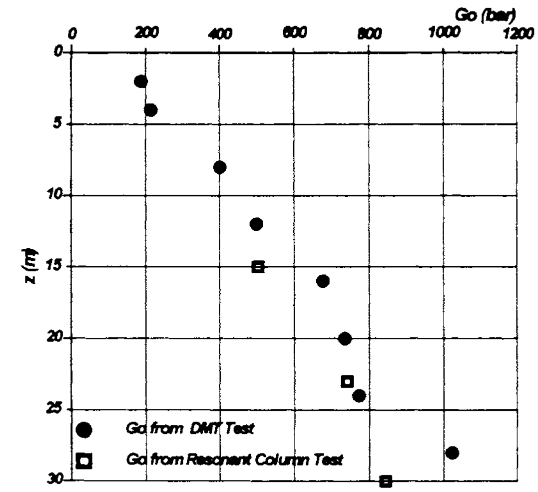


Fig.2 - G_o values from DMT and resonant column tests for Augusta clay

It seems that no resonant column tests or other laboratory tests were performed for dynamic soil properties evaluation in the cities of Patras and Roermond. No G-γ correlation to be used for soil response analysis is mentioned by Maurenbrecher et al (1995), while the correlation used for response analysis at the city of Patras is given in fig. 8 of the paper by Athanasopoulos (1995). However this correlation does not fit well with those reported by some Authors, as shown in fig.3. In fact the G-γ correlation for the Patras soil lies under the remaining correlation and also under the correlations obtained by Carrubba and Maugeri (1988) for the clay of Catania.

The Catania correlation given by equation (Carrubba and Maugeri, 1988):

$$\frac{G}{G_o} = \frac{1}{1 + 7.15\gamma\%^{1.223}} \qquad (3)$$

is very similar to that so far obtained for Augusta clay shown in figure 5 of the paper by Maugeri and Frenna (1995). It can be possible that the equation (3) could be used, instead of correlation shown in fig.8 of the paper by Athanasopoulos (1995) for a more appropriate evaluation of response analysis at the city of Patras. Similar considerations can be made for damping, D, evaluation. A comparison between the correlation D-γ used for soil response analysis at

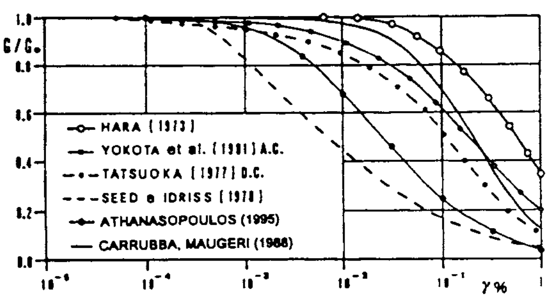


Fig.3 - Comparison of modulus degradation curves for different sites

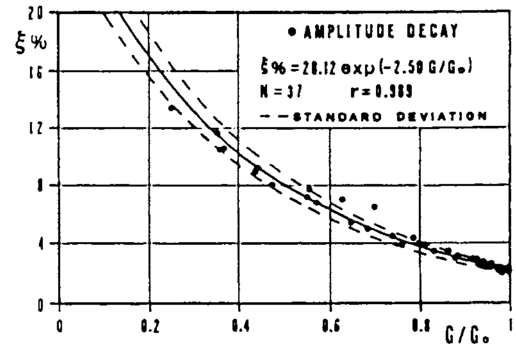


Fig.5 - Modulus degradation versus damping ratio for Catania clay (Carrubba and Maugeri, 1988)

Patras reported in fig.8 by Athanasopoulos (1995) and that given by some other Authors, is shown in fig.4. From this figure it can be seems that the correlation proposed for Patras soil lies over the remaining correlations and particularly over the correlations for Catania clay (Carrubba and Maugeri, 1988), which is given by the following expression:

$$D\% = 28.12 \exp\left[\frac{-2.50}{1+7.15\gamma\%^{1.223}}\right] \qquad (4)$$

valid for amplitude decay resonant column test analysis, and or by the expression:

$$D\% = 19.87 \exp\left[\frac{-2.16}{1+7.15\gamma\%^{1.223}}\right] \qquad (5)$$

valid for steady state resonant column test analysis.

A correlation can be established also between damping and normalized shear modulus G/G_o (fig.5); in this case eq. (4), valid for amplitude decay resonant column test analysis, becomes:

$$D\% = 28.12 \exp(-2.50\, G/G_o) \qquad (6)$$

4. Soil response and microzonation

The soil response analysis for the three earthquakes was carried out by three different computer code, all operating in one dimensional mode. The soil response was carried out: by means of the computer code SHAKE (Schnabel et al, 1972) for the Roermond earthquake, by means of the computer code LUSH2 (Lysmer et al, 1974) for the Patras earthquake and by means of a home made computer code (Maugeri and Frenna, 1987) for the Sicilian earthquake.

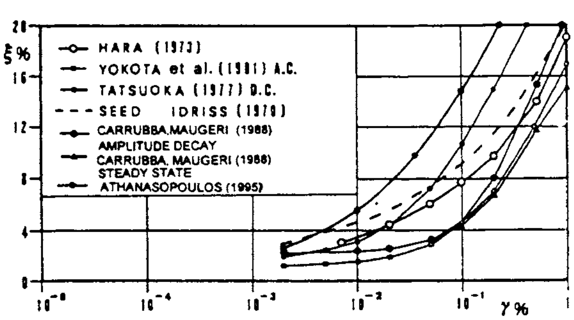


Fig.4 - Comparison of damping ratio curves for different sites

One dimensional modelling gives reliable results when a horizontal soil layer is enough large compared with its thickness as in the case of Mexico City; when usig one dimensional model it is possible to understand better the sensivity of the results to the range of variation of each geometrical and mechanical parameters of the model.

For long time the SHAKE and LUSH2 computer codes have been used and tested, while the computer code by Maugeri and Frenna (1987) has been not wide used but validation of the results so far obtained have been presented by the Authors (Maugeri et al, 1988; Maugeri and Frenna, 1993).

A comparison between soil response analysis results by means of the three different computer codes for the three cities of Roermond, Patras and Augusta (Sicily) cannot be easy made, because geometrical and mechanical properties of the soil profile are not all reported on the paper by Athanasopoulos (1995) and on the paper by Maurenbrecher et al (1995). However for soil profile at site1 of the city of Patras, assuming a profile of the unit weight of the soil given by the equation (Maugeri and Carrubba, 1985):

$$\gamma = 1.1129\, N_{SPT}^{\;0.163} \qquad (7)$$

and extrapolating the velocity profile of fig.3 by Athanasopoulos (1995) to deduct the shear modulus profile as shown in fig.6, the soil response to earthquake 1 evaluated by the computer code developed by Maugeri and Frenna (1987) is shown in figure 7. Comparing the results of figure 7 with those obtained in fig. 10 by Athanasopoulos (1995), it can be seems that the maximum acceleration is almost similar, as also ma-maximum shear strain and shear stress.

Considering soil degradation given by equations (3) and (4) soil response reported in fig.8, shows considerable bigger displacement, acceleration, shear strain and shear stress. This results so obtained, could not be generalized to all case but it can be stressed that a carefull evaluation of shear modulus degradation and damping can change substantially the soil response.

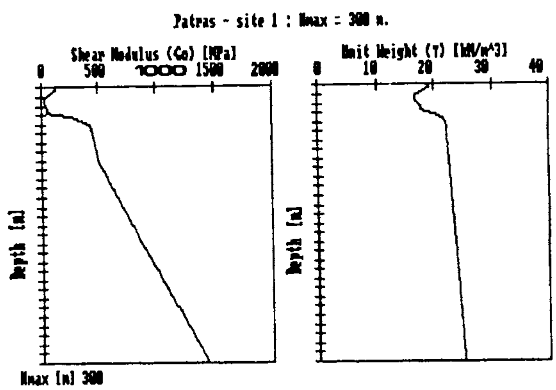


Fig.6 - Shear modulus and unit weight profiles, assumed for site 1 at Patras

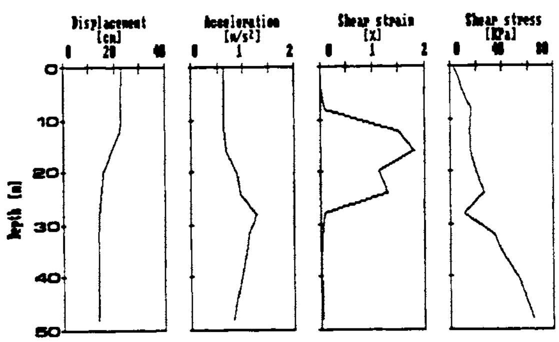


Fig.7 - Response analyses for site 1 at Patras, using soil properties profiles of fig.6

Soil response analysis is still an open problem, not because of computer codes, but because it depends strongly by the input earthquake at the bed rock, by a carefull soil properties evaluation and when the bed rock does not exist, by the depth of a "conventional" bedrock.

However soil response analysis is an usefull tool for microzonation study and for planning earthquake protection measures. To this aim the paper by Athanasopoulos (1995) is a good example of microzonation of a large city (population $\simeq$ 155.000) based on the results of 200 SPT tests performed inside 20 boreholes. By way of comparison, similar microzonation has been made for the small town of Calabritto (population $\simeq$ 3.500), destroyed by the 1990 Irpinia earthquake (Italy), based on the results of 200 SPT tests performed inside 41 boreholes (Maugeri and Carrubba, 1985) and for the city of Trapani (population $\simeq$ 70.000), where the microzonation was based on the results of 100 CPT tests and 100 boreholes.

Microzonation must takes into account land vulnerability due to landslides, soil densification, liquefaction, etc. To this aim the paper by Maurenbrecher et al (1995) gives very interesting case history on land vulnerability and on that the damage could be related very much to land vulnerability.

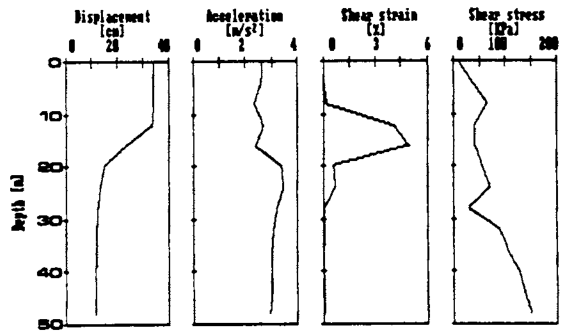


Fig.8 - Response analyses for site 1 at Patras using soil degradation given by eq. (3) and (4)

5. Conclusions

Lesson learned by occured earthquakes is very important to predict soil movements and for risk evaluation of future earthquakes.
To this aim soil response back-analysis of local intensities, is a very importat step to predict soil response for future earthquakes. However soil response analysis is affected by many uncertainties, as the input earthquake at the bedrock, the depth of bedrock and/or of the "conventional bedrock" and as the soil properties uncertainties expecially when in a large city, or even in a small town, where soil conditions greatly change from one site to another one.

In this case microzonation could be an usefull tool to predict local design earthquake, if microzonation criteria are based not on qualitativenly observation of damages but on soil response analysis, based on the results of an adeguate site investigation. Site investigation results allow to establish geotechnical model of local soil conditions to predict soil response for an earthquake equal or even bigger of those occured in the past.

Further researches are needed to understand if the soil response analysis, so far evaluated, can be a geotechnical model of the big one, as in the case of South-East Sicily, which was severely damaged by the 1693 earthquake, which caused about 60.000 victims (Postpischl, 1985).

Bibliography

Athanasopoulos G.A. (1994): "A new empirical correlation V_{so}-N_{SPT} and evaluation of its reliability". Proc. of Second Int. Conf. on Earthquake Resistant Construction and Design, ERCAD '94, Berlin, Germany, 15-17 June 1994.

Athanasopoulos G.A. (1995): "Site depend ground response for the city of Patras, Greece". Proc. Third Int. Conf. on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, April 2-7, 1995.

Hara A. (1973): "Dynamic characteristics of ground and its applications". Proc. 2nd Symposium on Ground Vibration, Architectural Institute of Japan, pp.33-39 (in Japanese).

Hryciw R.D. (1990): "Small-strain-shear modulus of soil by dilatometer". Journal of Geotech. Eng., ASCE, vol.116, No.7, pp.1700-1716.

Iwasaki T., Tatsuoka F., Yokota K (1977): "Results of laboratory test for shear modulus on undisturbed clay". Proc. 12th Annual Meeting JSSMFE, pp.433-436 (in Japanese).

Lysmer J., Udaka T., Seed B.H., Hwang R. (1974): "LUSH 2: A computer program for complex response anaysis of soil-structure systems". Earthquake Engineering Research Center, Report No.EERC 74-4, April 1974, University of California, Berkeley, Ca.

Marchetti S. (1980): "In situ tests by flat dilatometer". Journal Geotechnical Eng., ASCE, vol.106, No.3, pp.299-321.

Maugeri M., Carrubba P. (1983): "Correlazione in situ della velocità delle onde di taglio con i valori N_{SPT}". Atti XV Convegno Nazionale di Geotecnica, Spoleto, 4-6 Maggio, vol.III, pp. 203-208.

Maugeri M., Carrubba P. (1985): "Microzoning using SPT data". Proc. X ICSMFE, San Francisco, 11-15 Agosto, vol.4, pp.1831-1836.

Maugeri M., Frenna S.M. (1987): "Modello isteretico semplificato per la determinazione della risposta dei terreni in campo non lineare". Atti 3° Convegno Nazionale: L'Ingegneria Sismica in Italia, Roma, 30 Settembre - 2 Ottobre, vol.II, pp.269-288.

Maugeri M., Carrubba P., Frenna S.M. (1988): "Frequenze e modi di vibrazione di terreni eterogenei". Rivista Italiana di Geotecnica, vol.XXII, n.3, pp.163-171.

Maugeri M., Frenna S.M. (1993): "Amplificazione delle onde di taglio durante il terremoto del Mexico del 1985". VI Convegno Nazionale: Ingegneria Sismica in Italia, Perugia, 13-15 Ottobre (Report unpublished).

Maugeri M., Frenna S.M. (1995): "Soil-response analyses for the 1990 South-East Sicily earthquake". Proc. Third Int. Conf. on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, April 2-7, 1995.

Maurenbrecher P.M., Den Onter A., Luger H.J. (1995): "Review of geotechnical investigations resulting from the Roermond April 13, 1992 earthquake". Proc. Third Int. Conf. on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, April 2-7, 1995.

Postpischl D. (1985): "Atlas of isoseismal maps of Italian earthquakes". C.N.R., Progetto Finalizzato Geodinamica, Roma.

Schnabel B., Lysmer J., Seed H.B. (1972): "SHAKE, a computer program for earthquake response analysis of horizontally layered sites". Report No.EERC 72-12, University of California.

Seed H.B., Idriss I.M. (1970): "Soil moduli and damping factors for dynamic response analysis". Report No.EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley, December 1970.

Tatsuoka F (1977): Riportato in Iwasaki et al (1977).

Yokota K., Imai T., Konno M. (1981): "Dynamic deformation characteristics of soils determined by laboratory tests". OYO Technical Report, No.3, pp.13-36.

Discussion on paper titled: "Observed Surface Breakage Due to Strike-Slip Faulting", by C.A. Lazarte and J.D. Bray, (Paper No. 9.10)

By: G.A. Athanasopoulos, Assoc. Professor, Dept of Civil Engineering, University of Patras, GR-26500, Patras, Greece.

The authors present very interesting information in a well written paper. The discusser believes that the full description of the response of a site to earthquake loading should include analyses of propagation of both types of disturbances i.e. seismic waves and bedrock fault rupture. The paper concetrates on the subject of propagation of strike-slip bedrock faulting in the overlying soil deposits. A distinctive feature of the work presented in the paper is that it compares observations of ground deformation developed during an actual earthquake to observations obtained from a small scale physical model. The fact that qualitative agreement was found to exist between the two sets of observations indicates that may be possible, in the near future, to obtain quantitative results from small scale physical models. The discusser, in an attempt to further clarify some points of the paper, would like to ask the authors to address the following issues:

1. Have the authors examined the possibility of reducing further the dimensions of the physical model and run the tests in a centrifuge?

2. It is stated in the paper that the motion of the split base of the model simulates the movement of a vertical, strike-slip fault. Does this imply that another model configuration could be devised, in order to simulate inclined fault movement?

3. The discusser agrees with the authors that the rate of shear rupture propagation may affect the propagation pattern of the fault in the soil and this subject deserves further examination. Could the authors give some numerical values of the expected rate of shearing in actual faults, during earthquakes?

4. Could the authors make further comments on the effects of boundary conditions on the deformation (or rupture) pattern developing in the physical model tests?

5. Could the authors present photographs of the deformed surface of soil in the physical model tests as well as of the testing device?

Discussion on paper titled: "Damage to Agricultular Facilities Caused by the 1993 Kushiro-Oki and Hokkaido Nansei-Oki Earthquakes", by S. Tani, (Paper No. 9.15)

By: G.A. Athanasopoulos, Assoc. Professor, Dept of Civil Engineering, University of Patras, GR-26500, Patras, Greece.

The author presents an interesting survey of damage to agricultural facilities caused by two recent (1993) Japan earthquakes having their epicenters off the coast in the northern part of Japan. Both earthquakes had a magnitude $M = 7.8$ whereas the focal depth of one of the earthquakes was 107 km and of the other 34 km.

The discusser believes that the paper contains valuable material (observations) that should be the subject of future investigations and analyses, e.g. the behavior of fill dams. In the meantime it would be of interest if the author could address the following points:

1. Did the different focal depths of the two earthquakes produce any recognizable differentiation of damage patterns and extent?

2. Could the author provide diagrams illustrating the observation that the damage to farm roads occured in the boundary area between the cut and the bank over a ravine and that the damage was greater when the thickness of the soft ground layer was increased?

3. Are there any results available from the analytical study of the behavior of the damaged Niwa-Ikumine dam?

Discussion on paper titled: "Review of Geotechnical Investigations Resulting From the Roermond April 13, 1992 Earthquake", by P.M. Maurenbrecher, A. Den Outer and H.J. Luger, (Paper No. 9.16)

By: G.A. Athanasopoulos, Assoc. Professor, Dept of Civil Engineering, University of Patras, GR-26500, Patras, Greece.

The authors present valuable information on the geotechnical investigations that followed the Roermond April 13, 1992 earthquake ($M = 5.8$) in the SE Netherlands. It is worth mentioning that these investigations made almost exclusive use of Cone Penetration Test results. According to the information reported in the paper, the CPT seems to be well suited to geotechnical earthquake engineering investigations and provides data that can be used in site-response analyses, and liquefaction susceptibility and slope stability evaluations. The discusser agrees with the authors that less destructive earthquakes - like the Roermond earthquake - deseve intense study and investigation and can provide valuable data and enhance our understanding of soil behavior under earthquake loading. A great amount of information is "compressed" into the limited available space of the paper and for this reason the discusser feels that the following points need clarification:

1. What is the reliability (quantitatively) of values of dynamic shear modulus, G, derived from the end bearing values, q_c, of CPT?

2. It is known that site response analyses are sensitive to the relations $G/G_o = f(\gamma)$ used to describe the non-linear behavior of soil material (Vucetic and Dobry, 1991). What were the pertinent relations used in this paper? They were the ones build-in the older version of SHAKE or some site-specific relations were developed?

3. Under what assumptions were the volumetric stains and settlements of soil layers, derived from the values of shear strains estimated by the program SHAKE?

4. Some more comments would be useful, regarding the reasons for which the 1987 study did not classify the Brunssum as a liquefaction susceptible area.

REFERENCE: Vucetic, M. and Dobry, R. (1991), "Effect of Soil Plasticity on Cyclic Response", Journal of Geotechnical Engineering, ASCE, 117(1), 89-107.

Discussion on paper titled: "Soil-response Analyses for the 1990 South-East Sicily Earthquake", by M. Maugeri and S.M. Frenna, (Paper No. 9.17)

By: G.A. Athanasopoulos, Assoc. Professor, Dept of Civil Engineering, University of Patras, GR - 26500 Patras, Greece.

The authors present results of seismic soil response analyses for the Saline site of Augusta, a town located in the south-eastern part of Sicily. The town was shaken by an $M = 5.4$, small epecentral distance, earthquake on 13 December 1990, which caused 19 deaths and severe damage to the buildings located in a reclaimed portion of land previously occupied by salt-ponds (Saline site).

The results of analyses indicate a rather intense amplification of the base motion at Saline site and compare well with the recorded motion at the surface of a similar soil profile at Catania. The approach taken in the paper and the obtained results manifest the great value of performing site response analyses by using site-specific values of dynamic soil properties and the recorded rock motion as the input motion. Due to the importance of the subject matter of the paper the discusser feels that the following points deserve further clarification by the authors:

1. It is stated in the paper that a "certain agreement" has been found to exist between laboratory and in-situ values of low-amplitude shear modulus, G_o, and a value of G_{oLAB} = 130 MPa is reported for a depth equal to 46 m. The in-situ value of low-amplitude shear wave velocity, V_{so}, at the depth of 46 m is equal to V_{so} = 600 m/sec, according to the diagram of Fig. 2. Thus, the in-situ value of shear

modulus can be calculated as $G_{oFIELD} = \rho V_{so}^2$ which gives: G_{oFIELD} = 680 MPa. It is thus found that $G_{oFIELD} \approx 5.2\ G_{oLAB}$ a fact that contradicts the statement of "certain agreement" made by the authors. The discusser has made several such comparisons (G_{oLAB} vs. G_{oFIELD}) in the past and has provided an explanation of the disagreement between values of G_o measured by resonant column and cross-hole tests in cohesive soils (Athanasopoulos, 1993).

2. It is not made clear in the paper whether for the site response analyses the G/G_o vs. γ and ξ vs. γ curves of Fig. 5 and Fig. 6 were used throughout the soil profile or a seperate set of curves was used for the surface layer of grey silty clay. Also, the depth to water table at the Saline site is not given in the paper.

3. No description is given in the paper of the computer code used to estimate the 1-D soil response. The discusser feels that since the cited reference is not in the English language, a brief description of the "monodimensional hysteretical-simplified method" could be of value to the reader.

REFERENCE: Athanasopoulos, G.A. (1993), "Estimation of the Age of a Marl by Dynamic Testing", Proceedings of the International Symposium on Geotechnical Engineering of Hard Soils-Soft Rocks, Athens, Greece, Sept. 1993, A.A. Balkema Vol. 1, 351-358.

Paper No. 9.04

Reply by G.A. Athanasopoulos, Assoc. Professor,
Dept of Civil Engineering, University of Patras,
GR-26500, Patras, Greece

The author would like to thank M. Maugeri for his interest in the paper. The discusser presents his comments divided into three groups: effect of dynamic soil properties, methods of analysis of seismic soil response and criteria for microzonation. The author will address these comments in the aforementioned stated order. Before proceeding further, however, he would like to provide some information on the damages caused by the 14-7-1993 Patras earthquake.

The earthquake resulted in minor damage (i.e. cracking of interior hollow brick infill walls) to a limited number of modern two to six story, reinforced concrete buildings. However, many old, one or two story, buildings with masonry (stone or brick) bearing walls suffered heavy damages and were rendered uninhabitable with most of them marked for demolition. Five thousand people were left (temporarily or permanently) homeless whereas one death due to heart failure was attributed to the earthquake. The direct repair cost of the earthquake was estimated to be $ 12 million.

On the subject of dynamic soil properties the discusser finds that the empirical correlation V_{so}-N_{SPT} developed by the author and used to convert N_{SPT} vs. depth profiles into V_{so} vs. depth profiles for the Patras sites is in agreement with a similar correlation developed for the Calabritto clay soil. However, no such an agreement was found to exist between the G/G_o vs. γ_c and D vs. γ_c relations used in the paper and the pertinent relations developed by Carrubba-Maugeri (1988) for the clay of Catania. The author would like to make clear that at the time the paper was written experimental results for the G/G_o vs. γ_c and D vs. γ_c relations were not available for the city of Patras and for this reason the seismic response analyses were performed by using one of the sets of curves built in the program LUSH2. Some resonant column test results for the clay of Patras did become available later, however, and they are shown in Fig. 1. The results shown in the diagram of Fig. 1 were obtained by the author (using his homemade Resonant Column Device) and by the Hellenic Central Laboratory of Public Works, CLPW, (using a Stokoe Resonant Column Device). The diagrams of Fig. 2 show average curves G/G_o vs. γ_c and D vs. γ_c, that are based on the test results and were used in reanalyzing the seismic response of all sites mentioned in the paper. In this context, it should be mentioned that at the Geotechnical Engineering Laboratory of the University of Patras has been developed a

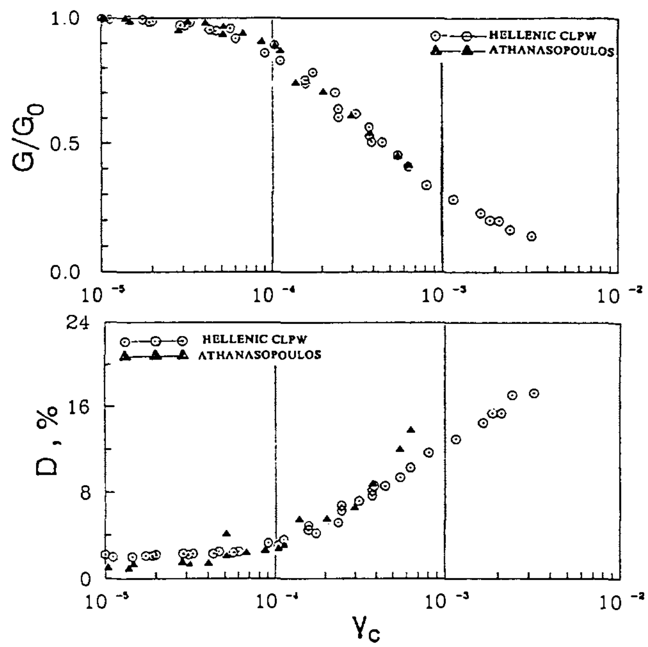


Fig. 1. Resonant column test results for the Patras clay.

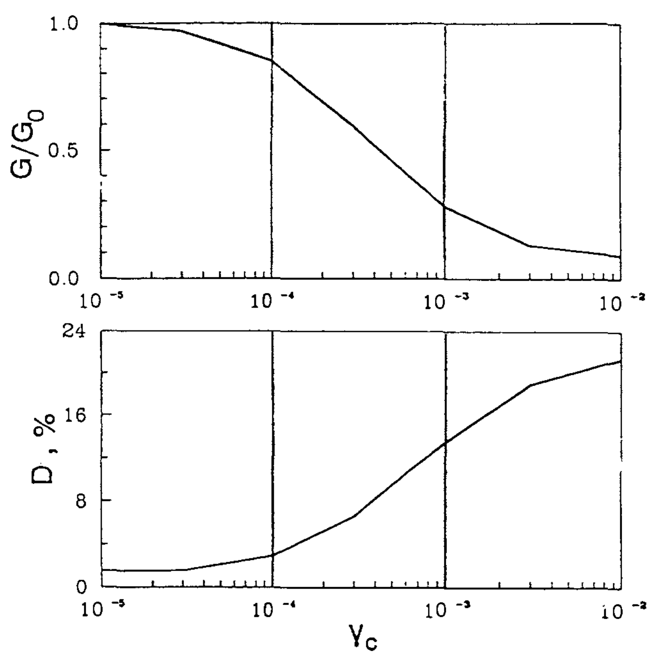


Fig. 2. Average G/G_o vs. γ_c and D vs. γ_c curves used in reanalyzing the seismic response of Patras sites.

simple program,called MODASM, that determines and plots the G/G_o vs. γ_c and D vs. γ_c relations for any soil material, provided the plasticity index (PI) of the material and the mean effective stress (σ'_o) acting at a particular depth are known. The program is written in *Visual Basic*, operates in the Microsoft Windows environment, and is based on the equations proposed by Ishibashi and Zhang (1993). The diagrams of Fig. 3 show the G/G_o vs. γ_c and D vs. γ_c relations estimated by the program MODASM for the clay of Patras (PI = 10, $\sigma'_o \approx 50$ kPa). In the same diagrams are superimposed the average curves based on the resonant column test results, shown in Fig. 2. A relatively good agreement is found to exist between the predicted and the experimental values of damping ratio whereas the experimental G/G_o values fall underneath those predicted by MODASM. For comparison purposes the diagrams of Fig. 4 show the values of G/G_o ratio and damping ratio, D, determined by using the empirical relations of Carrubba-Maugeri (1988) for the Catania clay, superimposed to the curves generated by MODASM. Again, the agreement between the damping ration values is good; however, in this case, the G/G_o ratio values lie above the MODASM curve and the deviation is rather significant. It should be noted that the program MODASM is available free of charge and can be accessed by sending e-mail at: tbp@ prometheus.hol.gr

On the subject of seismic soil response the discusser presents

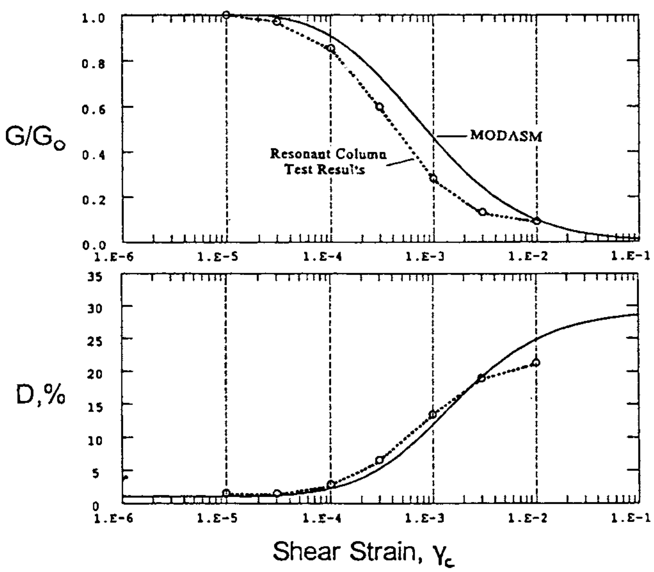
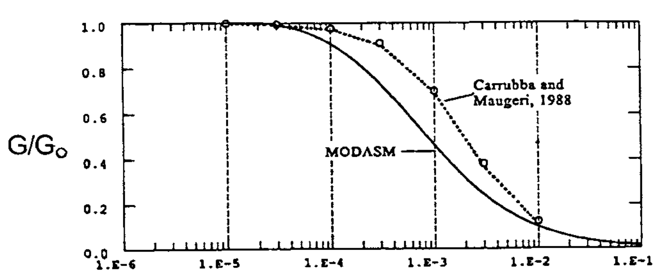


Fig. 3. Comparison between resonant column test results and the curves estimated by the program MODASM.



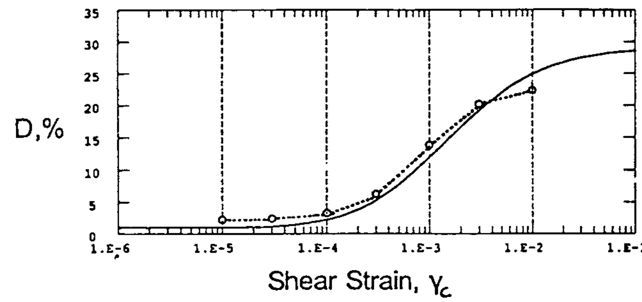


Fig. 4. Comparison between the Carrubba-Maugeri (1988) values and the curves estimated by the program MODASM.

results of a reanalysis for SITE 1 of Patras by using a computer program developed by Maugeri and Frenna (1987) that implements a one-dimensional equivalent linear analysis. The results agree well with those reported in the paper and the discusser concludes that the use of different computer codes does not, in general, produce significant differentiations in the estimated seismic soil response.

The discusser also presents results of a further reanalysis of the response for SITE 1 of Patras by using G/G_o - D - γ_c values derived from the Carrubba - Maugeri (1988) empirical relation. The results indicate that the response is significantly intensified, a fact that should be expected given the elevated position of the G/G_o vs. γ_c curve compared to the curve used in the paper. In this context the author would like to present the results of response analysis for SITE 1 of Patras obtained by using the computer program SHAKE91 and the site-specific data obtained by resonant column tests and shown in Fig. 2. According to these results, shown in Fig. 5, the response has been intensified, though not significantly. Nevertheless, the results indicate that in general, the shape of G/G_o - D - γ_c curves can have an appreciable effect on the estimated response of a site.

Finally, on the subject of microzonation studies the author concurs with the opinion of the discusser that seismic soil

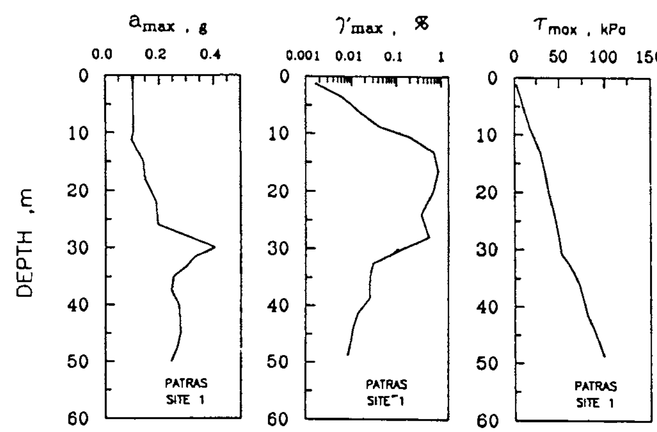


Fig. 5. Results of response analysis for SITE 1 of Patras, by using the program SHAKE 91 and site-specific soil properties.

response back-analyses is a useful tool for planning counter-earthquake measures, provided site-specific soil properties are available from adequate site investigations.

REFERENCES

Idriss, I.M and Sun, J.J., (1992), "User's Manual for SHAKE 91", A modification of the original SHAKE program published by Schnabel, Lysmer and Seed in 1972, Earthquake Engineering Research Center, Nov, 1992, University of California, Berkeley, Ca.

Ishibashi, I. and Zhang, X. (1993), "Unified Dynamic Shear Moduli and Damping Ratios of Sand and Clay", Soils and Foundations, Japanese Society of Soil Mechanics and Foundation Engineering, Vol. 33, No. 1, 182-191, Mar 1993, pp. 182-191.

Authors' Response to the Discussion of the Paper # 9.10

Observed Surface Breakage due to Strike-Slip Faulting

by Carlos.A. Lazarte and Jonathan.D. Bray
Graduate Student Researcher and Assistant Professor, Department of Civil Engineering University of California, Berkeley, CA 94720-1710

The authors wish to thank the discusser for his interest in this study on surface breakage due to strike-slip faulting. The authors agree with the discusser that a complete description of the problem requires the consideration of both the base deformation and accompanying strong ground motion. The focus of this study was to analyze the permanent ground deformation and fracturing as a result of a quasi-static (although rate-dependant), monotonic base displacement as a first step to understanding the most relevant factors in this complex problem.

Responding to the discusser's specific questions, the authors considered the possibility of using a centrifuge to study this problem. However, this and past studies (e.g. Sutherland, 1988; Bray et al., 1993) suggest that this type of physical modeling (i.e., using a soft clay mixture in a 1g environment) can provide reasonable results, which are similar qualitatively to observations made in the field, as long as the prevalent kinematic conditions are correctly reproduced. Kinematic conditions (i.e., boundary conditions and the material's ability to deform) are a dominant aspect in this problem, and they appear to be suitably reproduced with this experimental arrangement (Lazarte and Bray, in preparation).

Kinematic effects on the models' response derived from boundary conditions were also studied. A variable-height wall normal to the simulated fault's strike was placed to simulate varying boundaries conditions at the models' end faces. Minimizing these boundary effects from the end faces is important in this problem, and centrifuge modelling places restrictions on how far away boundaries may be placed. Nevertheless, the authors believe that centrifuge studies would serve to investigate other effects, such as confinement on the deformation and breakage pattern of sands models, which would be unrealistically dilative in a 1g low-confinement environment.

The authors also agree that future studies need to focus on the examination of other fault geometries, and perhaps more importantly, the simultaneous occurrence of horizontal and vertical slip along the fault's plane. The Bray et al. (1993) study focused on dip-slip faulting in cohesive soils, and our study focused on a purely strike-slip mechanism.

Understanding that the discusser is referring to the shearing rate as the base displacement rate, the authors would like to point out that the base displacement rate can be directly related to the rupture propagation velocity along the fault's strike. In theory, the limiting velocity of propagation of a vertically strike-slip is the earth's crust shear wave velocity (approximately 3.2-3.5 km/sec). The observed velocity of propagation in soil (much softer than the earth's seismogenic zone) should be a fraction of the above indicated value. Nevertheless, this dynamic process is more complex and other aspects not considered in this study are presented by Sholtz (1993). In this study, the base displacement rate was varied to investigate the effects of material ductility (the clay mixture was a shearing rate-dependant material) on the soil's response to underlying faulting. Finally, some photographs will be included in another publication (Lazarte and Bray, in preparation).

References

Bray, J.D., R.B. Seed, and H.B. Seed (1993). "1-g Small-Scale Modelling of Saturated Cohesive Soils", Geotech. Testing Journal, ASTM, **16**, No. 1, 46-53.

Lazarte, C.A, and Bray, J.D. (in preparation) "A Study of Strike-Slip Faulting Using Small-Scale Models".

Scholz, C.H. (1990). "The Mechanics of Earthquake and Faulting", Cambridge Univ. Press, Cambridge.

Sutherland, H. B.(1988). " Uplift Resistance of Soils," Geotechnique, Vol. 38, No. 4. 493-516.

Paper No.: #9.16
Reply by: ir. A. den Outer & P.M. Maurenbrecher, M.Sc.

In reply to the discussion given by M. Maugeri and G.A. Athanasopoulos the authors would like to give the following remarks.

On the completeness of data
It is clear that the paper, which represents a compilation of work carried out to date on geotechnical aspects of the Roermond earthquake of 1992, is based on data which is incomplete due to inadequate registration (clipped seismographs) and limited resources (the Netherlands had no specific group of workers or funding dealing with earthquakes). Present efforts can almost be considered voluntary, but hopefully through publications and discussions with more experienced and knowledgeable colleagues from more seismically active countries the research will gradually not only reflect present state-of-the-art but also contribute towards further understanding of earthquake hazard assessment and earthquake resistant building. Since the Rolla, Missouri conference a significant publication has appeared on the Roermond Earthquake (1) from which a number of themes touched upon in our paper are given in more detail.

On the relation of G/G_0
The relation of G/G_0 has been estimated by the computer program SHAKE. As indicated above little further investigations were done for in-situ shear tests to determine the shear velocities of the foundation soils. The shear wave velocities for Dutch soil can be exceedingly low in the region of 80 m/s. The use of computer codes such as SHAKE give an indication of the shear moduli. Further work is proceeding

together with the KNMI (meteorological office) seismology division to determine the response of building structures to low intensity induced earthquakes with the use of SHAKE.

On the use of CPT-data

The Dutch Cone Penetration test (CPT) is the most common method of site investigation for foundations in the Netherlands since the 1930s and increasingly is used world-wide as an acceptable test for foundations in preference to the much more error prone SPT. Unfortunately the SPT precedes the CPT by about ten years and hence much work has been based on SPT N-values. Considerable correlation work has been carried out between the two test forms (such as Schmertman (2) in the USA or reported in the ISOPT 1 Conference (3)) and hence one can use the empirical SPT- earthquake relationships such as liquefaction susceptibility and there has even been a Japanese (4,5) researcher who relates N-values to shear moduli. Cone tests have been developed to allow direct determination of ground shear velocities and hence shear moduli.

Later research on liquefaction potential in the Netherlands showed that a method published by Olsen (6) could be used well in combination with CPT-data.

On the use of alien expertise culture

A. den Outer expressed some concern during the discussion in Session IX, with regard to the use of earthquake engineering expertise for engineering practitioners confronted with a major once-off seismic event in a region of low-seismicity. Low-seismic countries often do not have the funds, national organisations or institutes to do earthquake research.

One criticism that could be levelled at those in the forefront of research in earthquake hazard engineering is that their work should be made more comprehensible to those suddenly confronted with the situation such as that in the Netherlands. The often seemingly complex field of ground dynamics and its interaction with engineering structures can be quite daunting to those attempting to record and analyze the damage caused by a once in a life-time event. Such workers may be adding to the hazard by making their work incomprehensible to those wanting to make simple practical steps to mitigate earthquake loading hazards. The impression remains that the earlier semi-empirical models such as developed by Seed and Idriss (7) in determining the liquefaction hazard has not really been superseded because such work is comprehensible and easy to apply. Subsequent workers have only refined the margins without significantly, say, contributing further towards hazard mitigation except by making the modelling a good deal more complex and hence less amenable to general engineering practitioners; an extra hazard to contend with!.

The same comparison can be levelled to computer code. Those codes which are not "user friendly" rarely meet success despite their sophistication and mathematical legitimacy. Such codes often suffer from demands not easily satisfied such as requiring parameters which are difficult to obtain so that additional laborious parametric and probabilistic studies have to be resorted to creating further complexity and confusion.

An honest mathematician should indicate such limitations and state the true contribution made over preceding models. A small insignificant improvement with a good deal more mathematical baggage can hardly be considered as advancement. Practical examples seldom accompany such models to demonstrate their usefulness.

The application of empirical relations developed in alien countries can only be validated if the correct boundary conditions used for development of the relation are known to all users. It is disturbing that many publications on the development of these relations hardly give any or incomplete information on these boundary conditions. What may seem obvious to local researchers, with respect to soil type, thickness or design criteria, may be unknown by others.

Another problem in using the foreign expertise is the scale difference in the research. The geological setting in NW-Europe does not allow comparison with the seismotectonic region of Greece and Italy. The distance between the two regions might be insignificantly small in other countries, with respect to their seismotectonic setting, in Europe, however, this is not the case. Therefor, if foreign experts look at low-seismic area like NW-Europe, as has happened in the past, it is necessary that they realise the scale difference and as a consequence do more detailed analysis on for instance microzonation.

The authors are indebted to the discussers for their useful remarks and highlighting that there is considerable room for development in the Netherlands in earthquake research. The authors are also convinced that the growth in earthquake engineering knowledge will develop significantly over the coming years as a result of the Roermond earthquake and further stimulated by the occurrence of more frequent, low-intensity, induced earthquakes in the northern part of the Netherlands as a result of hydro-carbon extraction. The minimum aim remains to ensure that the great wealth of information such as the damage surveys carried out for assessing financial compensation will be properly archived so as to be readily available for future research.

References

1 Seismotectonics and Seismic Hazards in the Roer Valley Graben: with emphasis on the Roermond earthquake of april 13 1992, Geologie & Mijnbouw, Vol 73, Part 2-4
2 Schmertman (1977), Guidelines for Cone Penetration Test: Performance and Design, FHWA-TS-78-209, 104 p.
3 ISOPT-1 (1988), Penetration testing 1988, Proceedings of the first international symposium on penetration testing, Orlando, 20-24 March 1988, A.A. Balkema, Brookfield, USA
4 Onsaki & Iwasaki (1973), Soils & Foundations (Japan), Vol 13, No 4, pp 61-73
5 Ohta & Goto (1978), Earthquake Engineering and Structural Dynamics, No 6, pp 167-187
6 Olsen (1988), Using the CPT for Dynamic Site Response Characterization, Proceedings of the Speciality Conference on Earthquake Engineering and Soil Dynamics II - Recent Advances in Ground-motion Evaluation, American Society of Civil Engineers, No. 20, pp.374-388, New York, USA
7 Seed & Idriss (1970), A simplified procedure of evaluating soil liquefaction potential, Earthquake Engineering Research Centre, Berkeley, California, Report No. EERC 70-9